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THESIS

MOTION SICKNESS, CREW PERFORMANCE, AND REDUCED MANNING IN HIGH-SPEED VESSEL OPERATIONS

by

John J. Calvert, Jr.

December 2005

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MOTION SICKNESS, CREW PERFORMANCE, AND REDUCED MANNING IN HIGH-SPEED VESSEL OPERATIONS

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LIST OF ABBREVIATIONS AND ACRONYMS

ABCD	American, British, Canadian, and Dutch
ASW	Anti-Submarine Warfare
AT/FP	Anti-Terrorism/Force Protection
d	Motion Dose
DCP	Data Collection Period
HLD	Home-Land Defense
HSV	High Speed Vessel
HSI	Human Systems Integration
ISR	Intelligence, Surveillance, & Reconnaissance
L-D	Labyrinthine Defective
LCS	Littoral Combat Ship
MANPRINT	Manpower and Personnel Integration
MHQ	Motion History Questionnaire
MIF	Motion Induced Fatigue
MII	Motion Induced Interruptions
MIO	Maritime Interdiction Operations
MIW	Mine Warfare
MSAQ	Motion Sickness Assessment Questionnaire
MSDV	Motion Sickness Dose Value
MSI	Motion Sickness Incidence
MSSS	Motion Sickness Symptomology Severity
NBDL	National Biodynamics Laboratory

NSWC	Naval Surface Warfare Center
PAQ	Performance Assessment Questionnaire
PD-IRD	Preliminary Design Interim Requirements Document
PDA	Personal Digital Assistant
PDI	Pensacola Diagnostics Index
PMSQ	Pensacola Motion Sickness Questionnaire
PVT	Psychomotor Vigilance Task
SSQ	Simulator Sickness Questionnaire
SUW	Surface Warfare
VI	Vomiting Incidence

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EXECUTIVE SUMMARY

This study examined the effects of ship motion on motion sickness, adaptation, susceptibility and performance. Data were collected onboard HSV-2 SWIFT during four periods from May 2004 to April 2005. HSV-2 SWIFT was chosen to examine performance on a high speed vessel with a catamaran hull type and a small crew. Data were collected using handheld personal digital assistants (PDAs) with a performance task along with questionnaires. Of the four data collection periods, only during the May 2004 period was performance data collected.

There were high recorded sea conditions during the May 2004 period, but the seas stayed constant during the entire collection period. The remaining three collection periods saw calm to medium sea conditions.

Results found that a possible relationship may exist between crewmember performance, as measured by Lapses on the Psychomotor Vigilance Task (PVT), and Motion Sickness. A simple stimulus-response task was used to measure performance during the first study. Observations showed that adaptation to the ship motion occurred between day 2 and 3. Three of four data collection periods found that there was a relationship between the Motion History Questionnaire and motion sickness incidence. Lack of rough seas during the three of the four data collection periods made it difficult to determine if there were more significant relationships during the analysis. Recommendations were to conduct future data collection

during rough seas that have more variation in sea state and efforts should address how motion sickness affects crew performance and if crew performance is degraded to a level that will affect the ship’s missions, specifically the LCS’s missions of Surface Warfare, Anti-Submarine Warfare, Mine Warfare, and high speed operations.

I. INTRODUCTION

A. OVERVIEW

Future U.S Navy vessels will be required to operate with only a portion of the manning in today's vessels due to advances in technology and a goal of reducing manpower. By placing this requirement on vessels such as the Littoral Combat Ship (LCS), the Navy is requiring itself to change its way of thinking about how ships are manned and who is selected for duties onboard LCS. Human performance issues such as sleep, fatigue, and motion sickness must be examined more carefully prior to final manpower decisions regarding these ships.

In the past, a ship's complement was sufficient to replace watchstanders who were severely affected by ship motion. In future ships, with a reduced crew size, the ship's complement will not be able to replace these watchstanders. This thesis will examine the LCS missions and determine if the effects of motion will affect the ship's ability to carry out those primary missions. Another aim of this thesis is to be able to apply the findings to other high speed vessels.

Primary missions of the LCS include Mine Warfare (MIW), Anti-Submarine Warfare (ASW), and Littoral Surface Warfare (SUW) against small, highly armed boats (Littoral Combat Ship, 2003). The means to conduct these missions involves mission modules that can be readily installed or removed from the LCS. Taken directly from the LCS website,

> Speed and agility will be critical for efficient and effective conduct of the littoral missions. The LCS must be capable of operating at low speeds for littoral mission operations, transit

> at economical speeds, and high-speed sprints, which may be necessary to avoid/prosecute a small boat or submarine threat, conduct intercept operations over the horizon, or for insertion or extraction missions (Program Executive Officer Ships, n.d.).

Performance requirements for the LCS include Joint Littoral Mobility; Intelligence, Surveillance and Reconnaissance (ISR); Special Operations Forces (SOF) support; Maritime Interdiction/Interception Operations (MIO); Home-Land Defense (HLD); and Anti-Terrorism/Force Protection (AT/FP). The appropriate core system and Mission Package must be installed to conduct those performance requirements (Littoral Combat Ship, 2003).

In addition to the missions given to the LCS, there are also requirements that the ship be able to operate at high speeds, up to 50 knots in shallow waters. Depending on the sea state, speed, and mission being carried out, crew performance can be affected by ship motion, especially the performance of those members that are unadapted to the ship's motions (Littoral Combat Ship, 2003).

Requirements for sea state are set in the Preliminary Design Interim Requirements Document (PD-IRD) for the LCS (2003). Sea state characterizes conditions of a body of water using variables such as wave height and period, and wind (Bowditch, 1995). Appendix B is a sea state table (Littoral Combat Ship, 2003). At sea state 5, all systems are required to be fully capable. At sea state 6, the requirement is for continuous efficient operation given that the best possible course and speed are selected. At

sea state 8 and above, heading of the ship is selected to ensure mission essential subsystems survive without serious damage.

B. BACKGROUND

This thesis examined the effects of motion sickness on crew performance of the HSV-2 SWIFT (Figure 1) during the Atlantic crossing. Additionally, adaptability to ship motion was analyzed. Since the manning onboard the Littoral Combat Ship (LCS) will be reduced greatly in comparison to current Naval ships, this study of the small crew onboard the HSV-2 SWIFT may provide useful information for future manpower determination. Questionnaires and a performance task provided data for analysis.

Figure 1. HSV2 SWIFT (From: High Speed Vessel SWIFT Joins Navy, 2003)

Four studies were conducted between May 2004 and April 2005 onboard HSV-2 SWIFT. The May 2004 data collection was conducted during seakeeping trials plus crossing of the Atlantic Ocean. The December 2004 data collection was conducted during a MIW exercise in the Gulf of Mexico. The 10 April 2005 data collection was conducted with USMC participants on a one day transit. The April 2005 data collection was conducted during an Atlantic transit.

C. SCOPE, LIMITATIONS, ASSUMPTIONS, AND BENEFITS

This study was an observational study with no control group. All participants were volunteers; they were not randomly selected. Sea condition data was collected during the first week of the May 2004 period. The sea conditions remained relatively stable throughout the first week, even with researchers from Naval Surface Warfare Center (NSWC) Carderock directing the ship to conduct octagons to assess the effects of sea direction on the ship. Performance data was collected only during the May 2004 period.

Potential benefits of this study are the ability to make more informed decisions regarding manpower on future ships. These issues include what size crew is needed, what type of personnel are needed onboard, and if personnel should be screened for susceptibility to motion sickness prior to assignment. Currently, motion sickness is not a factor directly considered in a ship’s manning model. Data analyses were designed to be able to show if motion sickness should be a factor included in the manpower model.

D. HUMAN SYSTEMS INTEGRATION

Human Systems Integration (HSI) incorporates eight domains. Those domains are: Manpower, Personnel, Training, Human Factors Engineering, System Safety, Health Hazards, Survivability, and Habitability. Three Human Systems Integration (HSI) domains that will receive focus in this thesis. Those domains are defined by the U.S. Army's Manpower and Personnel Integration (MANPRINT) program and incorporated into HSI (Booher, 2003). The main HSI domains being discussed in this thesis are defined as:

> Manpower The number of human resources, both men and women, military and civilian, required and available to operate and maintain military systems.
>
> Personnel The aptitudes, experiences, and other human characteristics necessary to achieve optimal system performance.
>
> Human Factors Engineering The comprehensive integration of human characteristics into system definition, design, development, and evaluation to optimize the performance of human-machine combinations (Booher, 2003).

Human Factors Engineering forms the basis of this thesis by examining motion sickness and its effect on individual and crew performance will be the base of this thesis.

> Ship motions limit a crews' ability to perform essential command, control, and communications functions, navigation tasks, maintenance, responsibilities, and even the preparation of food. Additionally, and more importantly, emergency situations may become more threatening in a situation where only a portion of the crew is able to respond (Stevens & Parsons, 2002).

Additionally, manpower requirements are discussed in relation to appropriate crew size if motion sickness degrades crew performance to a degree that the mission will be negatively affected. Finally, personnel is the last HSI domain to be addressed. There needs to be verification that those personnel assigned to the high speed vessel are not extremely susceptible to motion sickness.

HSI requirements set in the LCS PD-IRD (2003) are listed as follows:

> a. Provide sufficient berthing for the simultaneous assignment of ship's company and mission detachments.
>
> b. Use a human-centered design approach to automate decision processes and optimize manning. Exploit technologies to the maximum extent practicable.
>
> c. Generic multi-model reconfigurable work-stations and consoles will be used to the maximum extent practicable.
>
> d. Maintain the health and well being of the crew.
>
> e. Provide medical care to assigned and embarked personnel.
>
> f. Provide administrative and supply support for assigned and embarked personnel.
>
> g. Provide on demand individual and team training, with mission rehearsal capability, both I in port and underway.
>
> h. Provide ship upkeep and maintenance.
>
> i. Provide physical security.
>
> j. Ensure safety of equipment, personnel and ordnance.

E. THESIS ORGANIZATION

Chapter II gives an overview of the literature on motion sickness, motion induced interruption, sopite syndrome, human performance in relation to motion sickness, and manpower requirements. Chapter III discusses the methodology used in this study. Chapter IV explains the analysis techniques and provides certain findings. Chapter V discusses the results and gives recommendations for future research.

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II. LITERATURE REVIEW

A. OVERVIEW

The literature review is divided into three sections: motion sickness; human performance; and manning.

B. MOTION SICKNESS

> Motion sickness, or kinetosis, is not a pathological condition, but is a normal response to certain motion stimuli with which the individual is unfamiliar and to which he or she is, therefore, unadapted; only those without a functioning vestibular apparatus of the inner ear are truly immune (Benson, 1988).

A study was conducted in the 1960s where researchers compared twenty participants with normal hearing to ten participants who were labyrinthine-defective (L-D). Labyrinthine-defective refers to a defective inner ear. The study was conducted on a small, shallow draft, round bottom sea-going tug with no stabilization gear. Waves during the study were estimated at 40 feet with roll displacement of 40+ degrees. The normal hearing participants were the control group. All participants were males who were in good health. The researchers found that the L-D participants showed little or no symptoms of motion sickness, while the entire control group did show signs and symptoms of motion sickness. Many in the control group were highly resistant to motion sickness in prior conditions (Kennedy, Graybiel, McDonough, and Beckwith, 1968). The study shows two important facts. First, L-D people are not susceptible to motion sickness and secondly, all individuals are susceptible to motion sickness if the conditions are right.

Motion sickness is not a typical illness, such as the common cold or flu, but it is a situational condition or disorder.

1. Causes and Theory

Though the term “motion sickness” was not used until 1881 by Irwin, motion sickness dates back to at least as far as the Greek mythology writers (Money, 1970). However, even with the knowledge that motion sickness existed, there was relatively little known about the cause of motion sickness. Motion sickness results from an individual’s exposure to real or evident motion (Mansfield, 2005). Researchers developed many theories about the cause of motion sickness. Reason and Brand (1975) developed the sensory conflict theory or the Theory of Intersensory Mismatch, which most researchers have come to accept as the explanation for motion sickness (Rose, 2004). Benson (1988) describes essentially the same theory as the Neural Mismatch Theory.

The Theory of Intersensory Mismatch is described as when the brain receives information about motion that does not match with the sensations of motion produced by other sensory systems or from past experiences. The mismatch is what causes motion sickness. Seasickness takes place when the visual system fails to detect motion while the vestibular system senses the bodily motion. For example, consider a person inside a ship with no window. The vestibular system recognizes the motion of the ship. The visual system sees the inside of the vessel as stationary which causes a mismatch between the vestibular and visual systems. The abatement of motion sickness results when the body is able to match the sensation of motion. Onboard a

ship, an easy way to reduce the mismatch is to walk outside and watch the horizon (Reason & Brand, 1975; Wertheim, 1998; Rose, 2004).

Sensory conflict is divided into two categories and into different types. The two categories are intersensory and intrasensory. Intersensory conflict refers to two systems, the vestibular and visual, processing incompatible signals. Type 1 intersensory conflict occurs when both the visual and the vestibular system indicate motion, but the systems do not agree based on previous experiences. Type 2 intersensory conflict occurs when one system processes input without the input from the other system. Intrasensory conflict is divided into two types and occurs when the signals in the inner ear do not agree. Type 1 intrasensory conflict occurs when the otoliths and semicircular canals do not agree on the direction or magnitude of motion, but both signal motion. Type 2 intrasensory conflict occurs when signals are processed from one but not the other (Stevens & Parsons, 2002; Griffin, 1990; Mansfield, 2005). The information on the categories of conflict is documented in the below Figure 2.

Type of Conflict	**Category of Conflict**	
	Intersensory (Visual – Vestibular)	**Intrasensory (Canal – Otolith)**
Type I	Visual and vestibular systems simultaneously signal different (i.e. contradictory or uncorrelated) information.	Canals and otoliths simultaneously signal different (i.e. contradictory or uncorrelated) information.
Type IIa	Visual system signals in the absence of an expected vestibular signal.	Canals signal in the absence of an expected otolith signal.
Type IIb	Vestibular system signals in the absence of an expected visual signal.	Otoliths signal in the absence of an expected canal signal.

Figure 2. Types and categories of sensory conflict (From: Griffin,1990).

McCauley, Royal, Wylie, O'Hanlon, and Mackie (1976) found that motion sickness can be predicted from the frequency and acceleration of oscillation, such as heave motion aboard a ship. Motion sickness sensitivity was maximized at just under .2 Hz and incidence increased with higher accelerations with sinusoidal motions of frequencies between .05 and .8 Hz and accelerations of more than 1 m s^{-2} as seen in Figure 3 (O'Hanlon & McCauley, 1974; Wertheim, 1998).

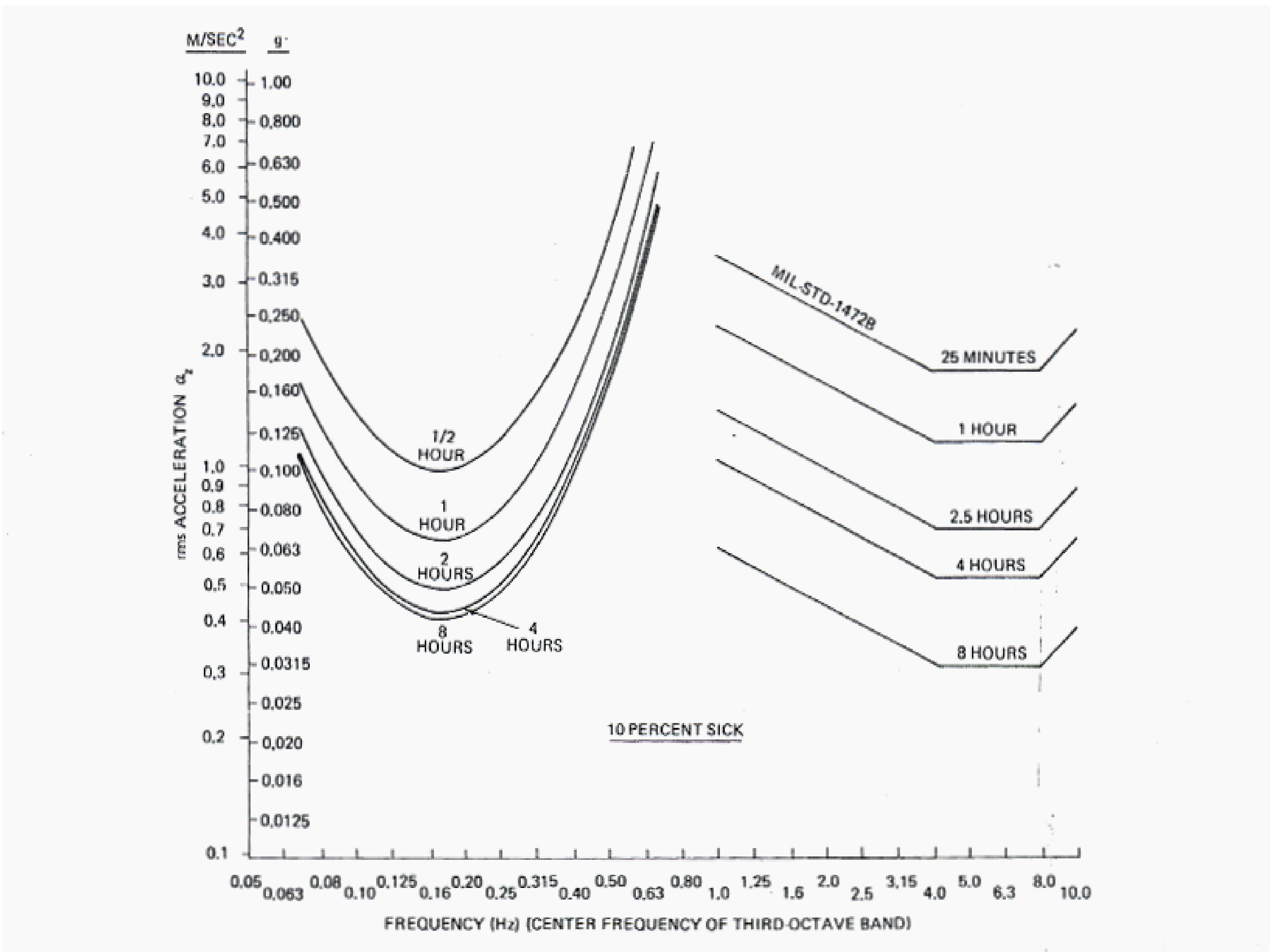

Figure 3. The 90 percent motion sickness protection limits for human exposure to VLFW. (The MIL-STD-1472B (and ISO 2631) FDP vibration limits from 1 to 10 Hz are included.) (From: McCauley & Kennedy, 1976).

Figure 4 is a model that shows factors thought to be involved in the causation of motion sickness. Factors that will be discussed in later sections include environmental, posture, age, gender, experiences, and mental activity. Each factor can influence motion sickness in different ways and at different levels (Griffin, 1990).

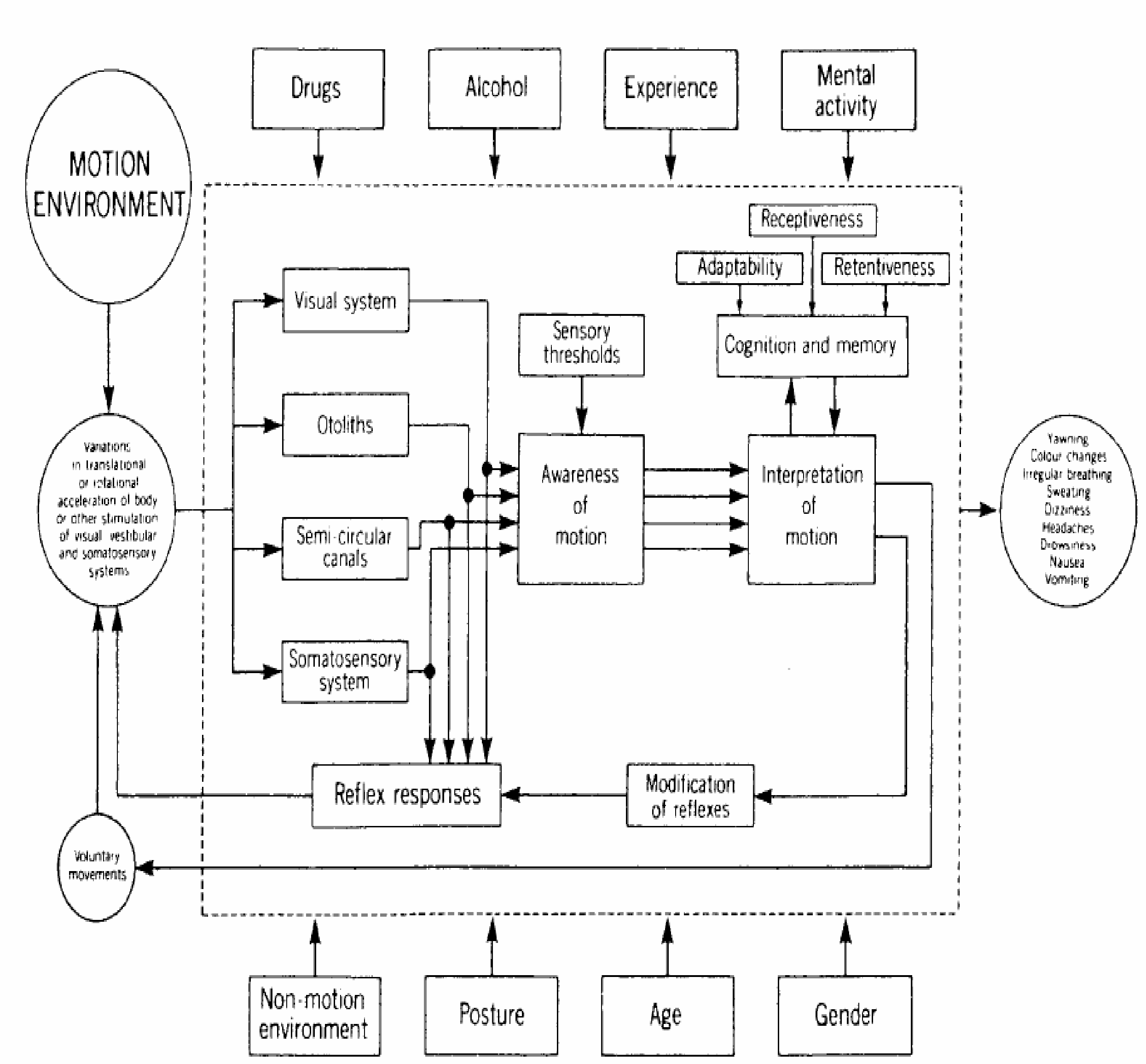

Figure 4. Conceptual model of factors possibly involved in the causation of motion sickness (From: Griffin, 1990).

Figure 5 lists some of the causes of symptoms of motion sickness.

CAUSES OF SYMPTOMS OF MOTION SICKNESS

Boats	Camel rides
Ships	Elephant rides
Submarines	
Hydrofoils	Simulators
Hovercraft	
Swimming	Fairground devices
Fixed-wing aircraft	Cinerama
Helicopters	Inverting or distorting glasses
Spacecraft	Microfiche readers
Cars	Rotation about off-vertical axis
Coaches	Coriolis stimulation
Buses	Low frequency translational oscillation
Trains	
Tanks	

Figure 5. Some examples of environments, activities, and devices which can cause symptoms of motion sickness (From: Griffin, 1990).

2. The Vestibular System

There is one essential feature for a human to experience motion sickness and that is a functioning vestibular system. The vestibular senses play a large factor in how a human experiences motion sickness. Humans are born with bilateral peripheral vestibular systems. (Kennedy et al., 1968, Wertheim, 1998; Wickens, 2004). An overview of the vestibular system is shown in Figure 6.

The subsystems in each inner ear consist of otoliths (vestibular sacs) and semicircular canals which jointly act as motion receptors. The receptors receive and send information to the brain in regards to the orientation and directional accelerations of the body. The three semicircular canals sense angular motion or rotational

accelerations around three axes which lie in orthogonal planes. The otoliths are sensors for linear accelerations which occur in any direction (Colwell, 1989; Wertheim, 1998; Wickens, 2004).

THE VESTIBULAR SYSTEMS

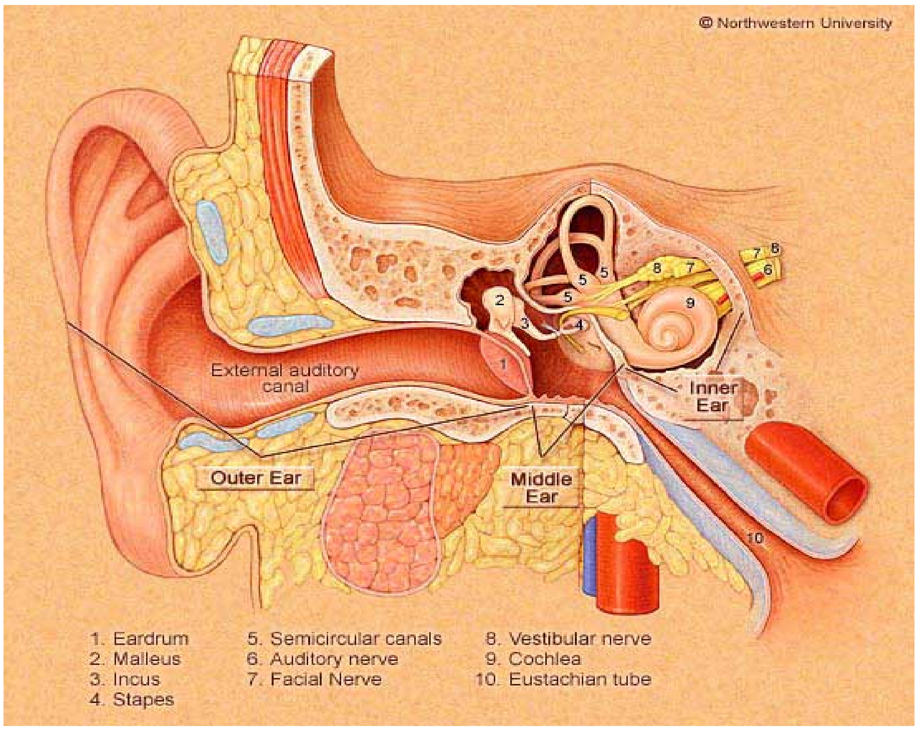

Figure 6. The vestibular system. Downloaded from http://www.tchain.com/otoneurology/disorders/bppv/otoliths.html on 14 November 2005.

Figures 7 and 8 show the two sets of otoliths, called the saccule and utricle, which sense the gravitational and linear acceleration. There are sensory hair cells attached to calcium carbonate stones in the otoliths. When there is a linear acceleration, the stones exert a force on the hair cells that in turn send a signal to the brain (Griffin, 1990; Hain, 2002).

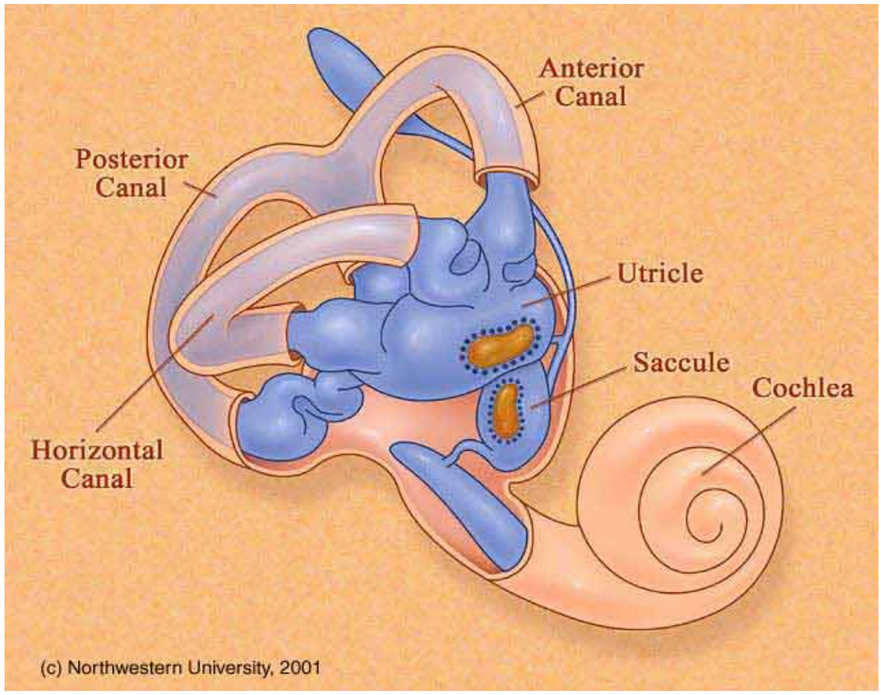

Figure 7. The semicircular canals. Downloaded from http://www.tchain.com/otoneurology/disorders/bppv/otoliths.html on 14 November 2005.

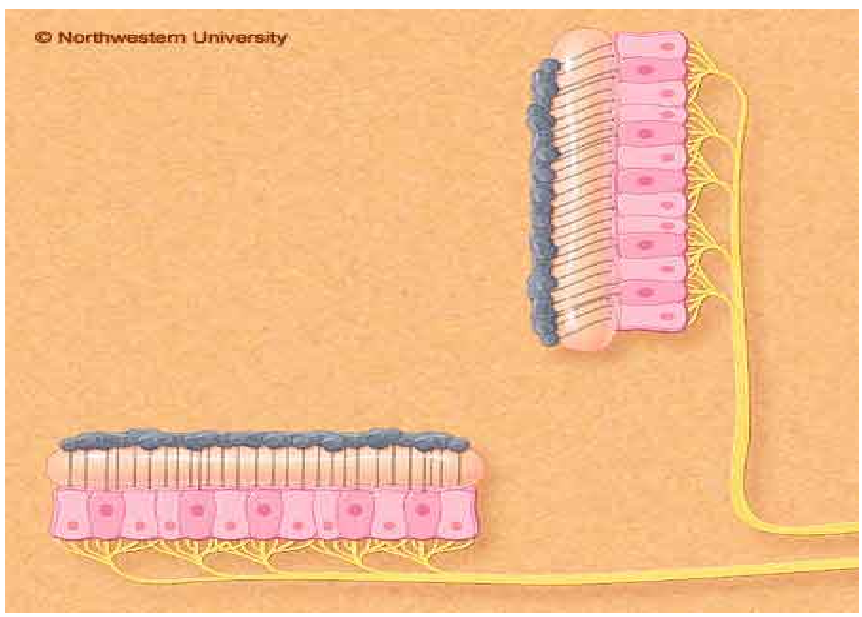

Figure 8. The otoliths organs. Downloaded from http://www.tchain.com/otoneurology/disorders/bppv/otoliths.html on 14 November 2005.

3. Signs and Symptoms

Symptoms of motion sickness can degrade the performance of an individual and reduce the desire to succeed or survive (Griffin, 1990). Signs of motion sickness are observable, while symptoms of motion sickness are not. The most common signs of motion sickness are pallor, cold sweating, and vomiting. The most common symptom is nausea (Money, 1970). Vomiting is the most visible result of motion sickness. However, a person can suffer from motion sickness without ever experiencing the sign of vomiting. A person can also experience sweating, drowsiness, yawning, loss of appetite, headache, lethargy, nausea, and pallor. A person can experience these symptoms without distress or pain. Additionally, Holmes, King, Stott, and Clemes research (as referenced by Mansfield, 2005) found that skin color (pallor) may change when experiencing motion sickness.

The signs and symptoms of motion sickness develop over time with the timeline reliant on the magnitude of the motion and individual susceptibility. However, individuals may not develop the same signs and symptoms in the same order. The sequence of the symptoms varies in regards to content, order, and the speed at which the symptoms develop. Yawning, bodily warmth, and stomach awareness are often the first symptoms to develop. A change in mouth dryness (either increase or decrease in salivation) follows the initial development of nausea and apathy. Generally the last symptom to occur in the process is vomiting, however that does not mean that motion sickness experience is over because earlier symptoms can resurface. Removal from the environment, or when the motion stimulus stops, will allow

an individual to recover from the motion sickness experience (Benson, 1988; Mansfield, 2005).

The timeline of symptom development can vary between minutes and hours. As symptoms become severe an individual can experience a “cascade effect” which means that the symptoms develop more rapidly. The “cascade effect” ends with the person vomiting, sometimes repeatedly (Reason and Brand, 1975; Brandt as cited by Mansfield, 2005). A person can be accustomed to the motion of a larger ship; however the effects of a smaller ship can cause a person to develop symptoms of motion sickness (Mansfield, 2005). Dobie and May (1990) found that there is some evidence that tolerance for one type of motion can be transferred to another type of motion. However, that transfer depended on the severity of the motion stimulus.

Quantification of symptom severity can be accomplished in different ways. A common way to quantify the severity is to determine the frequency of vomiting (O’Hanlon & McCauley, 1974). Different quantification methods will be discussed in a later section. Additionally, since not all people experience vomiting as a symptom, there are other methods for quantifying the symptoms of motion sickness (Griffin, 1990).

4. Susceptibility and Prediction

With future naval vessels designed for minimal manning, there is a need to ensure that individuals who are least prone to motion sickness are designated for assignment aboard ship. A way to determine who is susceptible to motion sickness is a medical screening. However, screening individuals for susceptibility is a difficult task. Many studies have been conducted to

determine how to assess susceptibility to motion sickness. A person's susceptibility to motion sickness is an individual trait (Griffin, 1990; Stevens & Parsons, 2002). For motion sickness at sea, or sea sickness, the incidence depends on sea state, vessel characteristics, individual characteristics, and other factors such as sleep, noise, etc. (Money, 1970).

Susceptibility to motion sickness varies between persons, inter-subject variability, and can be different during different occasions with the same person, intra-subject variability. The psychological factors such as personality, experience with the situation, and adaptability are individual factors. Individuals rely differently on vestibular, visual, and somatosensory senses and those differences can contribute to inter-subject variability (Griffin, 1990).

Susceptibility during low frequency motions has much to do with posture of the torso and head. Head motion is an important factor in susceptibility and there is a large variation between individuals in the movement of the head. Also, the direction of the motion in regards to the position of the head and body may play a role in susceptibility to motion sickness (Griffin, 1990).

Age is a large source of variability. Maximum susceptibility usually occurs between the age of 2 and 12. After 12 years of age, susceptibility slowly declines but may not disappear completely. There are many other individual traits that may have an effect on susceptibility to motion sickness. Susceptibility depends on the situation and the individual traits of the person (Money, 1970; Griffin, 1990; Stevens & Parsons, 2002).

While determining which personnel are most susceptible to motion sickness is critical, it is equally important to be able to understand and predict under what conditions individuals will experience motion sickness. Prediction of motion sickness is not an easy task considering all the variables that can play a role. Colwell (1989) documents two methods for prediction of motion sickness. The first method, developed by O'Hanlon and McCauley (1974), called Motion Sickness Incidence (MSI) takes the magnitude, frequency, and duration of vertical accelerations into account and computes a MSI percentage (O'Hanlon and McCauley, 1974; McCauley et al., 1976). The following equations are used to predict MSI:

$$MSI = 100\Phi(z_a)\Phi(z'_t)$$

$$z_a = 2.128\log(a) - 9.277\log(f) - 5.809(\log(f))^2 - 1.851$$

$$z_t' = 1.134z_a + 1.989\log(t) - 2.904$$

$$\Phi(-z) = 1 - \Phi(z)$$

Where $\Phi(z)$ is the cumulative distribution function of the standardized normal variable z, a is the RMS magnitude of the vertical acceleration (g), f is the frequency (Hz) of a, and t is the duration of exposure (min). The MSI model is depicted in the Figure 9. The figure shows MSI as a function of wave frequency and acceleration for a 2-hour exposure.

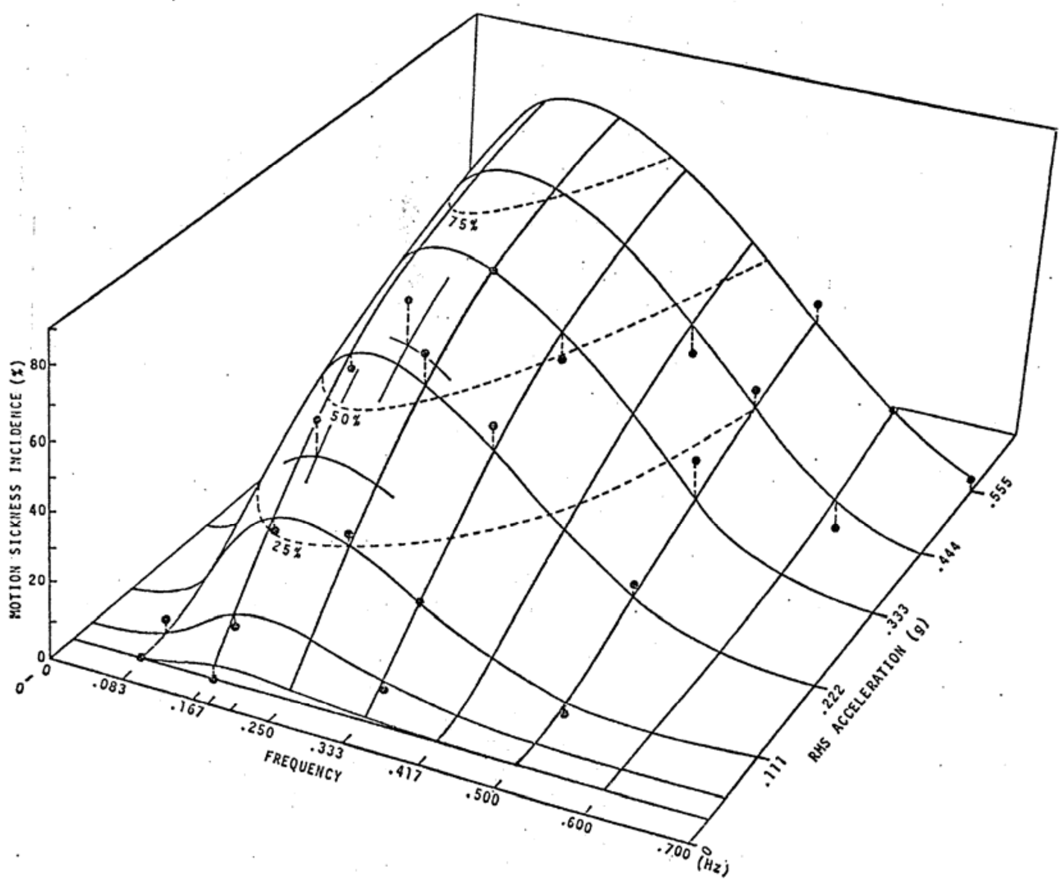

Figure 9. Three dimensional representation of the current model of Motion Sickness Incidence as a function of wave frequency and acceleration for 2 hour exposures to vertical sinusoidal motion (From: O'Hanlon & McCauley, 1974; McCauley et al., 1976).

The second method to predict motion sickness is Vomiting Incidence (VI) which is similar to MSI, but is calculated in a different manner (Lawther & Griffin, 1987).

$$VI = Kd = \frac{1}{3}d$$

Here K is constant at 1/3 and d is the motion dose which quantifies cumulative exposure to vertical acceleration.

$$d = (\int_0^T a_{fw}^2 (t) dt)^{1/2}$$

Figure 10.

Griffin (1990) describes a predictor for vomiting called the Motion Sickness Dose Value (MSDV). The MSDV is defined by the British Standard 6841 (British Standards Institution, 1987). With exposure of vertical oscillation in the frequency range of 0.1 to 0.5 Hz, the MSDV can predict the percentage of persons who will vomit. (Griffin, 1990; Stevens & Parsons, 2002) MSDV is defined as:

$$MSDV = (\int_0^T a_z^2 (t) dt)^{\frac{1}{2}}$$

From the MSDV, the vomiting incidence can be approximated by using the following equation:

$$MSI = K_m \bullet MSDV_z$$

where K_m is a constant. For unadapted adults, using K_m = 1/3 is recommended (Stevens & Parsons 2002; Griffin, 1990).

The Motion History Questionnaire (MHQ) was developed to help identify individuals who are more susceptible to motion sickness. A participant is asked about history of motion sickness in different environments. This questionnaire was developed solely for pre-exposure to motion. There have been numerous revisions and studies with the MHQ. (Kennedy, Frank, McCauley, Bittner, Root, & Binks, 1984; Kennedy, Lane, Stanney, Lanham, & Kingdon, 2001) To compute MHQ, the following equations can be applied:

1) MHQ = seasick + motsick + suscept + lizvolun + acsa
+ fslike + fsnaus + fssa + fsdiz.

2) MHQ = airsick + seasick + motsick + lizvolun + acsa
+ fslike + fsnaus + fssa + fsdiz.

Descriptions of each variable:

Airsick	How often Airsick?
Seasick	How often Seasick?
Motsick	Any other Sickness?
Suscept	How susceptible to MS?
Lizvolun	Chances of getting sick in experiment with 50% subjects sick?
Acsa	Stomach Awareness on Plane?
Fslike	Like Flight Sims?
Fsnaus	Nauseous in FS?
Fssa	Stomach Awareness in FS?
Fsdiz	Dizzy in FS?

To score each variable, the following values are applied:

Airsick: 0 = Never, 1 = Rarely, 2 = Sometimes,
3 = Frequently, 4 = Always

Seasick: 0 = Never, 1 = Rarely, 2 = Sometimes,
3 = Frequently, 4 = Always

Motsick: 0 = No, 1 = Yes

Suscept: 0 = Not at all, 1 = Minimally,
2 = Moderately, 3 = Very, 4 = Extremely

lizvolun: 0 = Certainly Would Not, 1=Prob. Would Not
2 = Probably Would, 3=Certainly Would

fslike: 0 = Like, 1 = Neutral, 2 = Dislike

fsvom, fsnaus, fssa, & fsdiz: 0 = None, 1 = Felt

(Kennedy, Fowlkes, Berbaum, & Lilienthal, 1992)

5. Response, Treatment, and Adaptation

The natural cure for preventing or curing motion sickness is adaptation (Stevens & Parsons, 2002). Adaptation is described by Money (1970) in terms of three different changes. The first is “the change in response to stimuli, especially a diminution of response”; the second is “the change in bodily mechanisms that is responsible for the response decline”; and the last is “the acquisition or the process of acquiring the change in body mechanisms.”

Additionally, Money (1970) describes habituation as "the process of acquiring the adaptive change and the decrease in response."

It is safe to assume that a person will adapt to ship motion with extended time at sea. The adaptation is vessel specific, especially when a person is adapted to a large vessel and then sails on a smaller vessel. A person who adapts to the larger vessel will not be adapted to the smaller vessel and stands a greater risk of becoming motion sick (Money, 1970).

Adaptation to motion sickness is essential to the success of a ship's mission. Rarely will a person be removed from a ship to recover from sea sickness. Adaptation is a successful motion sickness therapy. An individual's symptoms will decrease in severity with continued or repeated exposure to a particular motion. Typical adaptation occurs after two to four days of continuous exposure to the motion. However, if an individual is removed from the motion for a period of time and then returns to that same motion, that individual may experience the same symptoms as before. Adaptation is an individual trait in that individuals adapt to a certain motion at different rates. Individuals retain adaptation differently and differ in their ability to transfer adaptation from one motion to another. Approximately 5% of the population will never adapt to a motion (Benson, 1988).

Adapting to motion at sea can take anywhere from a few hours to a few days. As stated before, there are those few individuals who may never adapt. Individual differences play a key role in the adaptation process. The peak value of MSI over time for a population exposed to ship motions,

where MSI is the percentage of people who vomit can be seen in Figure 10. (Colwell, 1994; Stevens & Parsons, 2002)

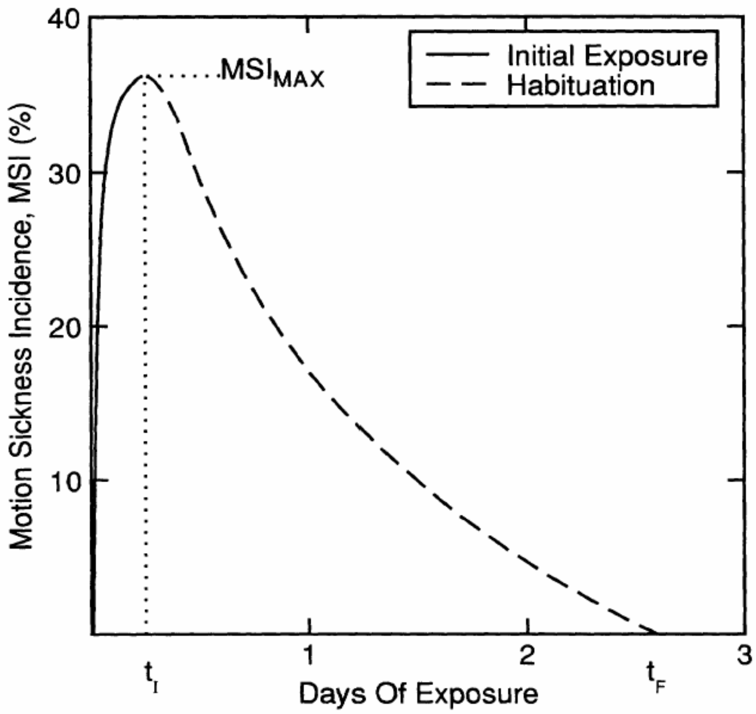

Figure 11. **Adaptation of Motion Sickness Incidence (From: Colwell, 1994)**

Dobie and May (1990) discussed how observations over time led researchers to believe that motion adaptation is specific to the certain motion by which it is acquired. They conducted a study that investigated how tolerance to one motion would generalize to other motion occurrences. If this generalization was corroborated, then they expected training in one area would transfer to tolerance in another area of motion. Results of the study found that there was some support that tolerance towards one area of motion would transfer to tolerance in other areas of motion. The severity of the motion stimulus used in the study played a role in the generalization of the tolerance. Dobie and May

(1990) found that the best way to create generalized adaptation is to utilize a very challenging, possibly vestibular, mode of stimulation.

Medication is an effective way to combat motion sickness. Not only is medication used to reduce the incidence of motion sickness, it is also used to reduce the time for acquiring habitation, and to decrease the effects of motion sickness symptoms. Reports indicate that approximately 12% of the naval community is medicated for motion sickness (Colwell, 1989). There are numerous anti-motion sickness drugs available that can help prevent or remedy motion sickness if taken at the appropriate time and in the appropriate amount. Medications can be given orally (preferred method), by transdermal patches, by nasal spray, by suppositories, and by injections. Proper timing is also essential for prevention of motion sickness. Medication taken orally needs to be taken at least one hour prior to experiencing any motion (Wood in Crampton, 1990).

The many different medications that can be administered either have central cholinergic blocking action or can enhance dopamine-norepinephrine activity. Scopolamine, atropine, dimenhydrina (Dramamine), cyclinzine, and meclizine are cholinergic blockers. The most successful drug in combating motion sickness was Scopolamine. The most successful antihistamine is dimenhydrinate, commonly known as Dramamine. Both drugs can cause drowsiness and dizziness. Scopolamine causes a reduction in performance for some people while Dramamine does not. For less drowsiness and dizziness, individuals should use Cyclizine. However, it is somewhat less successful than dimenhydrinate (Wood in Crampton, 1990).

6. Measuring Motion Sickness

Though there are many ways to predict an individual's susceptibility to motion sickness, there are fewer ways to measure the level or severity of motion sickness an individual experiences. Questionnaires developed to assess the level of motion sickness include the Pensacola Diagnostic Index (PDI) and the Pensacola Motion Sickness Questionnaire (PMSQ). Both of these questionnaires have limitations (Gianaros, Muth, Mordkoff, Levine, & Stern, 2001). Kennedy et al. (1992) developed and validated the Simulator Sickness Questionnaire (SSQ). The Motion Sickness Symptomology Severity (MSSS) scale was used in studies during trials with a US Navy SWATH vessel and a US Coast Guard Cutter to identify symptoms and assess the severity of those symptoms (Wiker & Pepper, 1978; Wiker, Pepper, & McCauley, 1980; Colwell, 1989).

Gianaros et al. (2001) states that even though the PDI is a good tool to assess MSI, its limitation is that it produces one score based on the symptoms of sweating, nausea, dizziness, warmth, headache, and drowsiness. They suggest using a multidimensional survey that can assess different syndromes under the overall MSI. The suggestion developed into a new questionnaire that is strongly correlated with the PDI, but can be broken down into the components of Gastrointestinal (G), Central (C), Peripheral (P), and Sopite-related (S). The name is the Motion Sickness Assessment Questionnaire (MSAQ) (Gianaros et al., 2001).

MSAQ scores are computed using the following formulas:

```
Overall score:          (sum of points from all items / 144)* 100
Gastrointestinal score: (sum of gastrointestinal items (G) / 36) * 100
Central score:          (sum of central items (C) / 45) * 100
```

Peripheral score: (sum of peripheral items (P) / 27) * 100
Sopite-related score: (sum of sopite-related items (S) / 36) * 100

(Gianaros et al., 2001)

Table 1 is a breakdown of the questions and the associated dimension.

Table 1. Motion Sickness Assessment Questionnaire (MSAQ) (From: Gianaros, et al., 2001)

Instructions. Using the scale below, please rate how accurately the following statements describe your experience.

Not at all Severely
1--------2--------3-------4--------5--------6--------7--------8-------9

1. I felt sick to my stomach (G)
2. I felt faint-like (C)
3. I felt annoyed/irritated (S)
4. I felt sweaty (P)
5. I felt queasy (G)
6. I felt lightheaded (C)
7. I felt drowsy (S)
8. I felt clammy/cold sweat (P)
9. I felt disoriented (C)
10. I felt tired/fatigued (S)
11. I felt nauseated (G)
12. I felt hot/warm (P)
13. I felt dizzy (C)
14. I felt like I was spinning (C)
15. I felt as if I may vomit (G)
16. I felt uneasy (S)

Upon computation of a score, the following scale is an estimate of the severity of motion sickness.

0-25	not sick
26-50	mild sickness
51-75	moderate sickness
76-100	severe sickness

E. R. Muth and M.E. McCauley (personal communication dated 17 June 2005.)

C. HUMAN PERFORMANCE

1. Overview

There are two requirements to assess human performance in a naval environment. One requirement is that the researcher needs a detailed and accurate description of the environment. The second requirement is the methodology for assessing human performance. Methods are well defined for

the ocean environment and motion prediction. However, quantifying the human performance aspect of the equation has proven to be difficult (Colwell, 1989).

Colwell (1989) suggests that four separate aspects should be investigated to assess human performance and the effects of motion: motion sickness; motion-induced interruptions (MII); motion-induced fatigue (MIF); and whole body vibration. Further suggestions include examining the interaction between all systems involved, verifying that a human is needed to participate, and deciding what events should be used to assess performance and the duration of each event.

The 1997 NATO Performance Assessment Questionnaire (PAQ) was administered to the crews of seven ships participating in a NATO exercise. The PAQ asked questions in reference to crew performance, motion sickness, and medication to treat motion sickness. For crew members suffering from motion sickness, the researchers found that more performance failures were present. Due to the increase in failures, the risk that the mission would fail increased dramatically. Additionally, the researchers were able to quantify the relationship between sickness severity and mission performance. As crew sizes decrease in future ships, they concluded that motion sickness will more strongly affect mission performance and could pose an even greater threat to overall mission performance (Bos, Colwell, & Wertheim, 2002).

The relationship between seasickness and task performance has been evaluated by many researchers. Schwab (as cited in Bos et al., 2002) found that in some cases, a person can be completely ineffective because they succumbed

so greatly to motion sickness. Other individuals can carry out tasks, but with less efficiency than a fully functional person. There is a difference between “peak efficiency” (emergency tasks) and “maintenance efficiency” (routine tasks) (Bos et al., 2002; Hettinger, Kennedy, & McCauley, 1990). Researchers here also found that a headache does not correlate with vomiting nor does vomiting correlate with nausea and stomach awareness. However, nausea correlates significantly with stomach awareness (Bos et al., 2002).

There is little evidence that performance in cognitive tasks is affected by motion. A review of research available on the effects of motion was divided into two categories. The first category was general effects which are tasks carried out in a moving environment. The second category was specific effects which interfere with human abilities (Wertheim, 1998).

General effects of motion sickness on performance include lowering of motivation which results in a slow work rate, the disruption of workflow, and possible abandonment of work. The effects of motion sickness vary by person and each person can be affected psychologically and physiologically. (Benson, 1988; Wertheim, 1998; Stevens & Parsons, 2002).

Motion Induced Fatigue (MIF), also known as Sopite Syndrome, has had little attention until recently. More research is needed on MIF because fatigue can affect cognitive performance. The American, British, Canadian, and Dutch (ABCD) working group has conducted studies in this research area (Wertheim, 1998). Physical fatigue was measured by oxygen consumption during work. By comparing the oxygen consumption with prior tests, a percentage is

calculated and referred to as "relative physical workload." That "relative physical workload" is related to the maximum amount of time in which a task can be carried out. Tests were also carried out in ship motion simulators and the researchers found that only a small increase in oxygen consumption occurred, even though the participants appeared fatigued (Wertheim, 1998; Stevens & Parsons, 2002).

From the results above, the researchers hypothesized that oxygen consumption increased only slightly in a moving environment, but the maximum capacity of oxygen consumption for a human body would be reduced. Two additional experiments were conducted and the results supported the hypothesis. The maximum capacity of oxygen consumption was reduced in a moving environment (Wertheim, 1998). These results confirm that working in a ship at sea will cause more fatigue working while in port.

Another factor that affects performance is biomechanical. Ship's motion affects postural control which can interfere with human performance. The loss or near loss of balance is referred to as Motion Induced Interruptions (MIIs). Models have been developed to predict the frequency of MIIs for a person standing during different ship movements. These models can then be used to determine if it is safe to perform certain tasks on ships (Graham, Baitis, & Meyers, 1992; Wertheim, 1998; Stevens & Parsons, 2002).

Crossland and Lloyd (1993) define MII which includes the following trends:

a. Stumbling due to a momentary loss in stability,

b. Sliding due to the motion induced forces overcoming the restraining frictional forces of crew shoes and moveable objects,

c. The very occasional, though potentially the most serious, conditions where the crew or object become momentarily airborne as the accelerations due to the motion of the ship exceed those due to gravity.

Research shows that motion induced decrements of performance may result when motion creates a lack of motivation because of motion sickness, balance issues, or motion induced fatigue. Motion can interfere with fine motor control or with visual detail of small objects, which needs to be considered in moving environments (Wertheim, 1998).

Wiker and Pepper (1978) conducted a study that measured the sensitivity of performance to a ship’s motion. Examples of performance measures used were navigation tasks, visual tasks, tracking tasks, and grammatical reasoning. They found that motion sickness severity increased or decreased depending on direction of the ship in relation to the swell. Head and bow seas caused greater illnesses than stern or quartering seas. Additionally, fatigue increased and there were changes in concentration with vessel motions. Interestingly, only some of the performance tasks degraded while others did not. Specifically, visual search performance was degraded while tasks such as arithmetic calculations were not degraded (Wiker & Pepper, 1978).

Dobie (2000) discussed research that was conducted at the National Biodynamic Laboratory (NBDL) Ship Motion Simulator. Based on numerous studies, Dobie stated that cognitive performance is not affected by provocative

motion. However, he noted that fine motor skills are degraded and there are subjective effects of motion sickness.

2. Psychomotor Vigilance Task (PVT)

A common approach for performance testing is the stimulus-response (S-R) method which presents visual or auditory stimuli to a study participant and requires that participant to respond in a timely manner (Dorrian, Rogers, & Dinges, 2005). The Psychomotor Vigilance Task (PVT) was developed to measure the effects of sleep loss on human performance (Dinges & Powell, 1985). Response Time (RT) and Lapses (RT greater than 500 ms) are the common performance metrics with the PVT. Dorrian et al. (2005) reported the intra-class correlation coefficients (ICC) as having a maximum reliability for the number of Lapses with an ICC = 0.888 and $p < .0001$. Similar results were obtained for PVT median response times. Even though mainly designed to assess sleep loss, the PVT is both reliable and valid. It was used to quantify the effects of alcohol on performance, the effects of drowsy driving on performance (Dorrian et al., 2005).

D. MANNING

1. Overview

Future U.S. Navy vessels will have significantly reduced crew sizes. Due to the reduced crew sizes, a ship's mission will depend even more on the individual efforts of each person onboard. Each person will be required to be fully functional and capable of performing essential tasks to assist the ship in completing the mission. Manning of

future ships will be increasingly difficult because factors that were not significant to manning models in the past will play significant roles in future manning models. As discussed previously, motion sickness and its effect on crew performance needs to be considered when manning ships such as the LCS.

2. Littoral Combat Ship

The Preliminary Design Interim Requirements Document (PD-IRD) sets the threshold level for core crew size at 50 members. The objective level is 15 core crew members. Add on mission-package crew and the totals rise to 75 and 110, respectively (Littoral Combat Ship, 2003). Douangaphaivong (2004) conducted an analysis of the feasibility of this small crew size its responsibilities. The analysis found that the baseline requirement was approximately 200 personnel. When accounting for Smart Ship and Fleet Optimal Manning Experiments, that baseline number was reduced even more. However, through a set of "paradigm shifts" the researcher found that the optimal manning of the LCS between the core crew and the mission modules was approximately 90 – 100 personnel (Douangaphaivong, 2004).

3. Current Navy Manpower Standards

The Navy Total Forces Manpower Requirements Handbook (April, 2000) from the Navy Manpower and Analysis Center describes the requirements and allowances for determining manpower. There are three allowances added to the base time which provide for personal needs, fatigue, and unavoidable delay. These allowances are applied as percentages to the normal time. Personal allowances include time for the worker to make trips to the rest room or to obtain water. Fatigue allowances include time for losses in work

production. There are no provisions for time lost due to motion sickness.

When determining a manpower model, the Navy assumes a vessel steaming in Condition of Readiness III (Condition III) with the crew in a 3 section watch rotation. Condition III is set during increased tension situations or when a ship is forward deployed while cruising. The Navy Standard Workweek (Afloat during Wartime) is defined in Table 2.

Table 2. Navy Standard Workweek (Afloat during Wartime) (From: Department of the Navy, 2002)

Ship Standard Workweek			81.00 hrs
Productive Workweek			70.00 hrs
Analysis of Duty Hours			
Total hours available weekly		168.00	
Less Non-Available Time:			
Sleep	(56.00)		
Messing	(14.00)		
Personal needs	(14.00)		
Sunday (free time)	(3.00)	(87.00)	
Scheduled On Duty Hours Per Week		81.00	
Less:			
Training	(7.00)		
Service diversion	(4.00)	(11.00)	
Total hours available for productive work		70.00	

The Navy Standard Workweek must be taken into account when determining manpower requirements. Douangaphaivong (2004) reported on past studies that confirmed the feasibility of ships reduced manning if proper technological advances are used. There will always be tradeoffs between mission efficiency, quality of life, and minimum manning. Those tradeoffs must be properly considered. Also of concern is the finding that, if moderate-risk technology is used, then minimum manning can

be significantly impacted (Gumataotao & Mennecke, 1997). A consideration that should be added to these findings is how motion sickness affects crew performance. If performance is degraded due to motion sickness and tradeoffs have already been made to use moderate-risk technology, then mission accomplishment could be in jeopardy.

III. METHODS

A. OVERVIEW

The purpose of this thesis is to analyze the effects of motion sickness on human performance in high speed naval vessels. Additionally, susceptibility and adaptation to motion sickness are analyzed to determine the effects on the crew. This section describes the data collection process to include the participants, instrumentation, and procedures.

B. PARTICIPANTS

All participants volunteered for this study and were U.S. military personnel or Department of Defense civilians. Participation in this study was anonymous. Data were collected during four different periods. The following table details each data collection period by the number of participants, the number of times the participants answered the survey, and the number of days of each data collection period.

Table 3. Data Collection Periods

Data Collection	**Original # of participants**	**# of participants completing survey at least once**	**# of surveys answered: Low Range**	**# of surveys answered: High Range**	**Number of Days**
DCP1 - May 04	19	17	5	49	15
DCP2 - Dec 04	21	15	1	27	14
DCP3 - 10Apr05	22	21	3	9	1
DCP4 - Apr 05	23	17	2	19	8

Table 3 gives a breakdown of each Data Collection Period (DCP). Each period started with an original number of participants who filled out the Pre-Questionnaire. The number of participants who continued to participate in each DCP dropped from the original number. The table also lists the minimum and maximum number of times a participant filled out the survey and for how long the each DCP lasted.

Table 4 breaks down the participant data between gender, military/non-military, rank range, age range, and time in service. Participants in all DCP's rated themselves to be in good physical conditions.

Table 4. Participant Data

	Gender (M/F)	Military	Non-Military	Military Rank Range	Age Range	Time in Service Range (yrs)
DCP1	17/0	15	2	E3 – O4	21-44	1-24
DCP2	13/2	15	0	E4 – O4	21-44	1.2-13
DCP3	21/0	20	1	E3 - E4	19-49	1 - 6
DCP4	14/3	17	0	E4 – O4	24-42	3 - 18

In the pre-questionnaire, all participants were asked if they were taking medication for motion sickness or any other illness. In DCP1, 2 of 15 were taking pain medications and listed them as being Motrin and Naproxen. One participant was taking motion sickness pills, but did not list the name. There were 7 of 15 participants who reported taking motion sickness medication (no specific name listed) and 2 of 15 were taking pain medication in DCP2. For DCP3, 10 of 21 participants took motion sickness medication (3 listed as Dramamine) and 4 were taking pain medications. Finally, for DCP4, 6 of the 17 participants were taking motion sickness medication (3 listed medication as Meclizine) and 1 participant was taking Tylenol.

C. INSTRUMENTS

1. Survey

Participants for each data collection period were given a pre-questionnaire and a questionnaire to be completed while at sea.

Pre-Questionnaire: Prior to the ship getting underway, the participants in each data collection period were asked to fill out a pre-questionnaire. The pre-questionnaire consisted of questions on general background, susceptibility to motion sickness, medical information, medication currently prescribed, and an initial motion effects questionnaire.

Questionnaire: DCP1 and DCP2 were both broken into three sections which reviewed motion effects, motion induced interruptions (MIIs), and sleep. DCP3 was tailored to Marine passengers and asked questions on motion effects and combat effectiveness. Finally, DCP4 presented questions on motion effects, MIIs, and sleep.

The four surveys used the same standardized motion effects questionnaire. The surveys used were the Motion History Questionnaire (MHQ) and the Motion Sickness Assessment Questionnaire (MSAQ). The MII section in three of the surveys was standardized. The Stanford Sleep Scale was used in the first two surveys in addition to other general questions on sleep. The last survey had only general questions on sleep.

2. Psychomotor Vigilance Task (PVT)

To test individual performance, the PVT was administered using hand-held devices. As discussed earlier, the PVT is a visual signal detection task. Each participant

was issued a hand-held device with a 5 minute version of the PVT installed. An example of PVT on the hand-held device is shown in Figure 11.

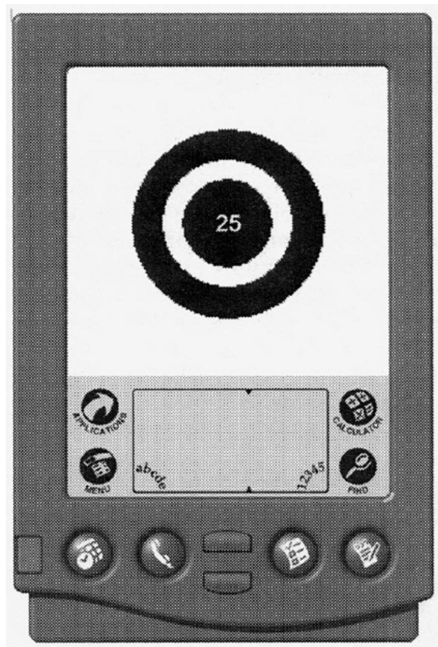

Figure 12. An example of the PVT (From: Thorne et al., 2005)

D. PROCEDURE

As listed in Table 3, there were four different data collection periods (DCP1 – DCP4) onboard the HSV. Different individuals served as research coordinators during each DCP. The researchers met with the participants onboard the HSV-2 prior to the ship getting underway during each data collection period.

During this meeting the researchers gave a brief introduction to the study to include purpose, time involved, and importance of the results. Participants were given descriptions of motion sickness, motion induced

interruptions (MIIs), and Sopite Syndrome. Participants were briefed that the survey was voluntary and they were allowed to stop at any time.

After the introduction, participants were asked to review and sign the applicable informed consent forms and then each was handed a pre-questionnaire. The researchers reviewed the pre-questionnaire with the participants to ensure that there were no questions. After the participants completed the pre-questionnaire, the questionnaires for the underway period were handed out and discussed. Participants were given instructions about how often and when the survey was to be completed. Participants were asked to fill out the survey as detailed below for each of the data collection periods:

A) DCP1 - Participants were to complete the survey at the beginning and ending of each duty period. Additionally, they were to complete the survey before the last meal prior to going to bed (if it took place at least 1 hour after completion of duty). Each participant was given a PDA with a charger to collect PVT data. The participants in on-duty status were instructed to take a PVT once per four hour watch (3 times per day) plus before going to bed. Participants in off-duty status were instructed to take the PVT before each meal and before going to bed. The PDAs were collected at the end of the collection period and the data were downloaded by the researchers.

B) DCP2 – Participants were to complete the survey at the beginning and ending of each duty period. Additionally, they were to complete the survey

before the last meal prior to going to bed (if it took place at least 1 hour after completion of duty).

C) DCP3 – For the single day data collection with the Marines, participants were asked to fill out the survey after getting underway at 1 hour, 2 hours, 4 hours, 6 hours, 10 hours, 14 hours, and the 18 hour marks. If the ship arrived prior to the 18 hour mark, then participants were asked to complete the survey just prior to arrival.

   Note: Only 20 out of approximately 200 Marines participated.

D) DCP4 – Participants were to complete the Sleep questionnaire each morning as they awoke. The Motion questionnaire was to be filled out four times per day: upon awakening and then every four hours thereafter until the participant went to sleep. Additionally, participants were to complete the survey every time there was a change in their condition.

The researchers met with the CO and XO to explain the procedures, to ensure compliance with the survey, and to ensure that participation in the research would not interfere with crew duties.

During DCP1, NSWC researchers onboard HSV2 directed the ship to drive in octagonal patterns for the first seven days underway to enable the analysis of direction of the seas on ship motion. As seen in Appendix A, there were 21 octagons recorded. Recorded data included date, time, significant wave height average, and wave period average.

E. DATA ANALYSIS PLAN

The data analysis examined Motion Sickness Incidence (MSI) and the effects on human performance. The PVT performance data were analyzed using the Mean Response Times and the number of lapses. Analysis reviewed the motion sickness adaptation phase onboard the HSV-2. Sea state was taken into account with the available data. Finally, using the pre-questionnaire data, the MHQ score was determined and analyzed in relation to MSI to determine if susceptibility can be predicted using the MHQ.

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IV. ANALYSIS AND RESULTS

A. OVERVIEW

Data analysis was divided into three subsets which included examining performance data in relation to motion sickness, examining susceptibility to motion sickness, and adaptation to the ship’s motion. DCP1 data was analyzed to determine if a relationship existed between MSI and the PVT. All four data sets were analyzed for susceptibility to motion sickness and all but DCP3 were analyzed for adaptation to the ship’s motion. MSAQ scores were computed for every trial a participant recorded. The percentage of individuals scoring a minimum of “Mild Sickness” for each data collection period is as follows: DCP1 - 52.9%; DCP2 – 20%; DCP3 – 61.9%; DCP4 – 23.5%.

B. MOTION SICKNESS AND PERFORMANCE

DCP1 was the only data set that included PVT data. The PVT performance measures were reaction time (RT) and lapses. A lapse is a reaction time greater than 500 ms (Dinges & Powell, 1985). Mean RT and lapses were computed for each 5 minute trial on each participant. In addition, mean RT was computed for the last minute of each 5 minute trial to determine if there is a performance drop during the last minute of every trial.

Overall MSI was computed using the MSAQ computation for each trial. Due to differences in time between the completion of each MSAQ and the completion of each PVT trial, data were matched as closely as possible.

Sea state was recorded for the first 7 days underway when NSWC Carderock researchers were directing the ship in octagonal patterns. After completing the 7 days of seakeeping trials, the ship began a straight transit across the Atlantic and sea state data were not available.

The Pearson method was used for analysis because the data is ratio scale with a zero point of 11.111 (Gianaros et al., 2001). A ratio scale is defined as "an internal scale with the additional feature of an absolute zero point. With a ratio scale, ratios of numbers do reflect ratios of magnitude" (Gravetter & Wallnau, 1996).

1. Descriptive Statistics

With 15 participants in DCP1, there were a total of 222 responses. The minimum and maximum responses were 2 and 20 respectively. The mean number of responses per participant was 12.59. Overall MSI ranged from 11.111 to 47.222 with a mean of 16.24. Mean RT for the five-minute period was 220.55 ms with a median of 198.69 ms. For the last minute of each trial, the mean RT was 277.05 with a median RT of 205.65. Wave height ranged from 6.21 ft to 9.84 ft with a mean of 8.16 ft. Wave period ranged from 6.8 sec to 11.7 sec with a mean of 9.07 sec.

2. Sea State

At first glance, it appeared that the sea state data collected during the seven days had little effect on performance data. The data ranged from Sea State 3 to Sea State 4. The mean sea state was 3.84 with a standard deviation of .37.

Figures 12 and 13 are boxplots of sea state and PVT performance measures. As can be seen in these figures, there is little variability in the data with respect to sea

state. There are some outliers that need to be addressed. In reviewing the raw data, Overall MSI was examined along with any comments from the participant. Overall MSI for each outlier showed all MSI scores to be in the "Not Sick" range. None of the outliers had comments.

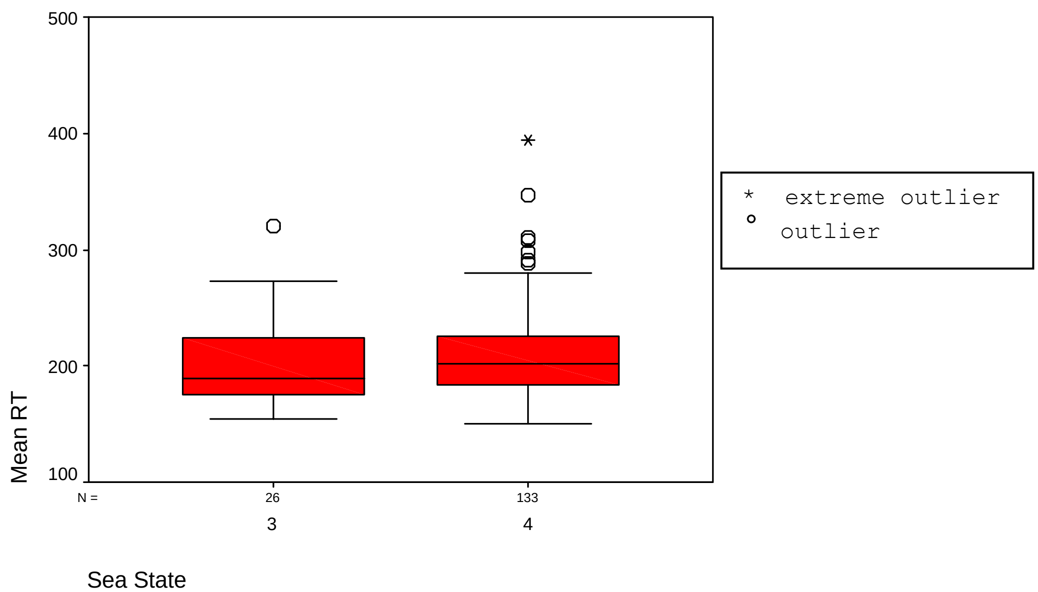

Figure 13. Boxplot: Mean Response Time and Sea State

When examining Figures 12 and 13, there were some extreme outliers that were not representative of the entire data set. Establishing a cutoff of three standard deviations from the Mean RT as an operational definition of "outlier", one extreme outlier was outside the upper bound of 470.077. For Lapses, there were two extreme outliers outside the upper bound of 10.636. By removing those extreme outliers that were not representative of the overall data set and performance being analyzed, it is possible to see that there is little variance in PVT performance as a function of sea state. For the remaining analysis, performance data were examined without the sea state data.

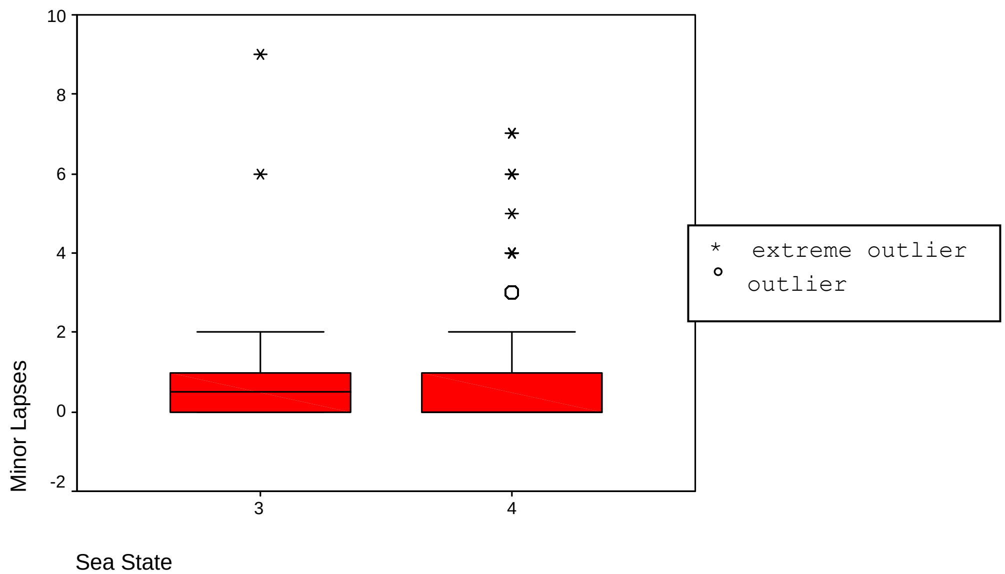

Figure 14. Boxplot: Lapses and Sea State.

3. Response Time

The next step in the analysis was to determine if a relationship existed between PVT performance data and the Overall MSI. The PVT performance data were broken into two different measures: Mean RT and Lapses. Each trial lasted five minutes. In addition to the five minute trial average performance data, the Mean RT was computed for the last minute of each trial to determine if relationships existed between the Overall MSI and the last minute of each trial. Previous studies showed that performance drops at the end of each trial (Dorrian et al., 2005)

As seen in Figure 14, a boxplot was completed for Mean RT and participant and shows considerable variability. To reduce the variability, another variable was created and called “Yscores.” Yscore was computed by removing the participant effect by ranking each participant’s data and

taking the inverse of the normal distribution. Figure 15 shows a boxplot of "Yscores" and the participant.

Computing a simple linear regression showed no significant relationship between Overall MSI and Mean RT. The p-value was .062 with an R^2 of .248. A linear regression was run using Overall MSI and Yscores.

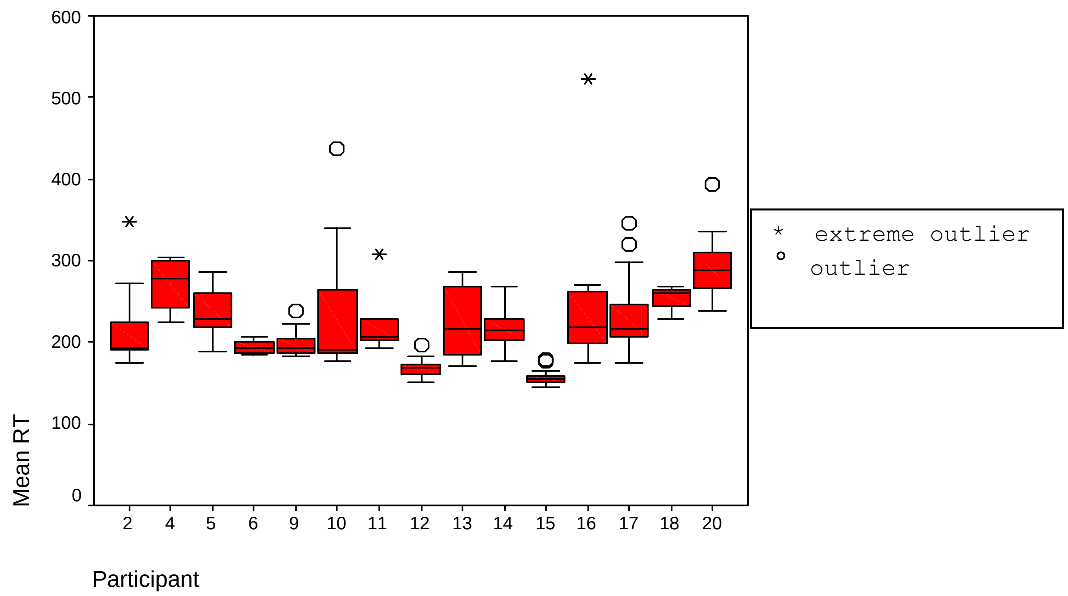

Figure 15. Boxplot: Mean RT and Participant.

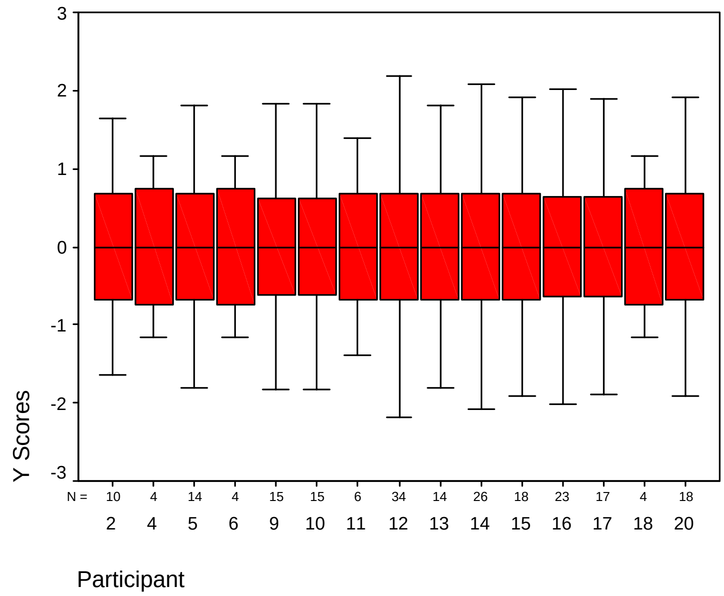

Figure 16. Boxplot: Mean RT(Y Score) and Participant.

A histogram (Figure 16) shows the normality of the Yscores data. Data analysis shows there was no significant relationship between Overall MSI and Yscores with a p-value of .201.

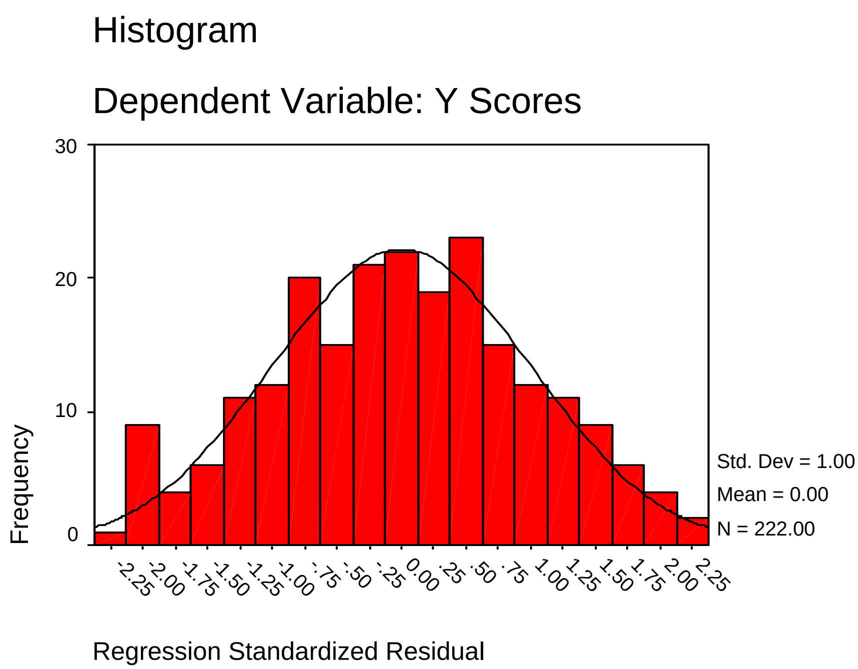

Figure 17. Histogram: Mean RT(Y Scores)

The next analysis conducted was on Overall MSI and the 4 to 5 minute mean RT. Boxplots (Figures 17 and 18) yielded similar responses to that of the overall means. The analysis was run using the 4 to 5 minute RT means. Correlation analysis shows there is no significance between overall MSI and the 4 to 5 minute mean RT (Yscore4-5). Using a linear regression gave the same result of no significant relationship with a p-value of .986.

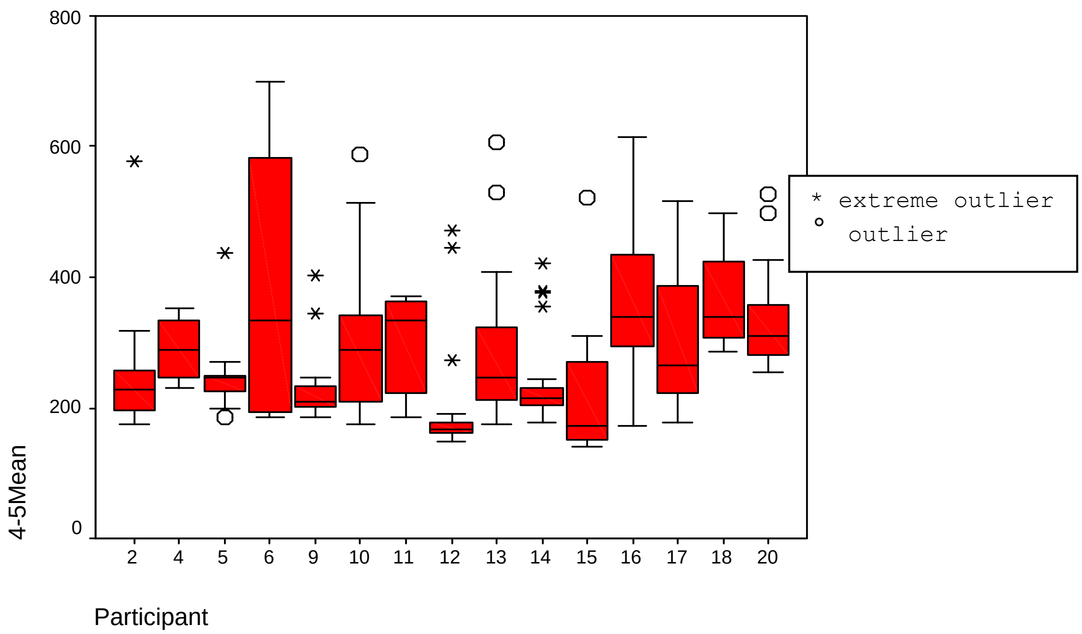

Figure 18. Boxplot: 4-5 minute mean RT and Participant

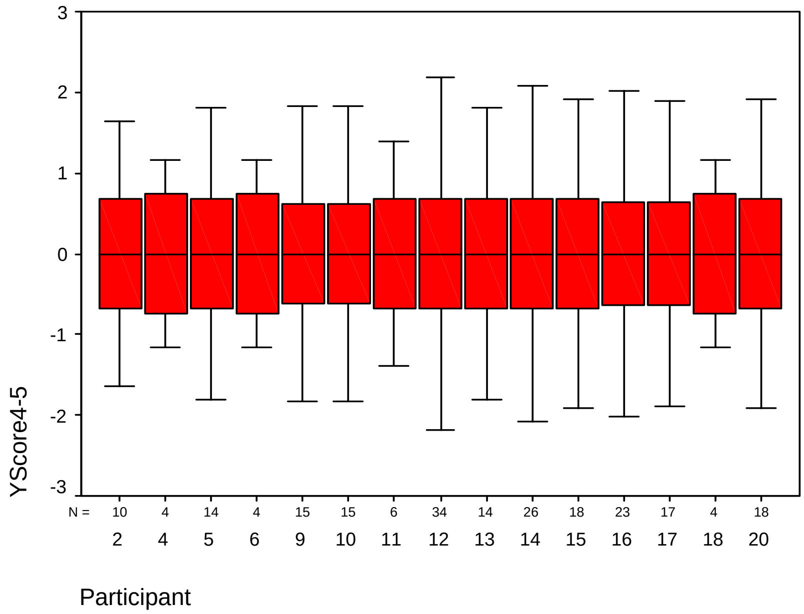

Figure 19.
Figure 20. Boxplot: 4-5 minute Mean RT(Y Scores) and Participant

Analysis thus far showed that no significant relationship existed between Overall MSI and the PVT performance data on reaction time. Analysis was then conducted using Overall MSI and the performance data on PVT Lapses. A boxplot for Lapses of each participant is shown in Figure 19. The boxplot shows that there is variability in the number of lapses among participants. Due to this variability, further analysis was needed.

A regression was run to determine whether there was a relationship between Overall MSI and Lapses. There was no significant correlation between Overall MSI and Lapses. Results of a one-tailed t-test were a p-value of .0445 with a t-value = 1.708. The results show that there is a marginal statistical difference between Overall MSI and Lapses. Furthermore, the statistics suggest that a relationship may exist between Overall MSI and PVT Lapses.

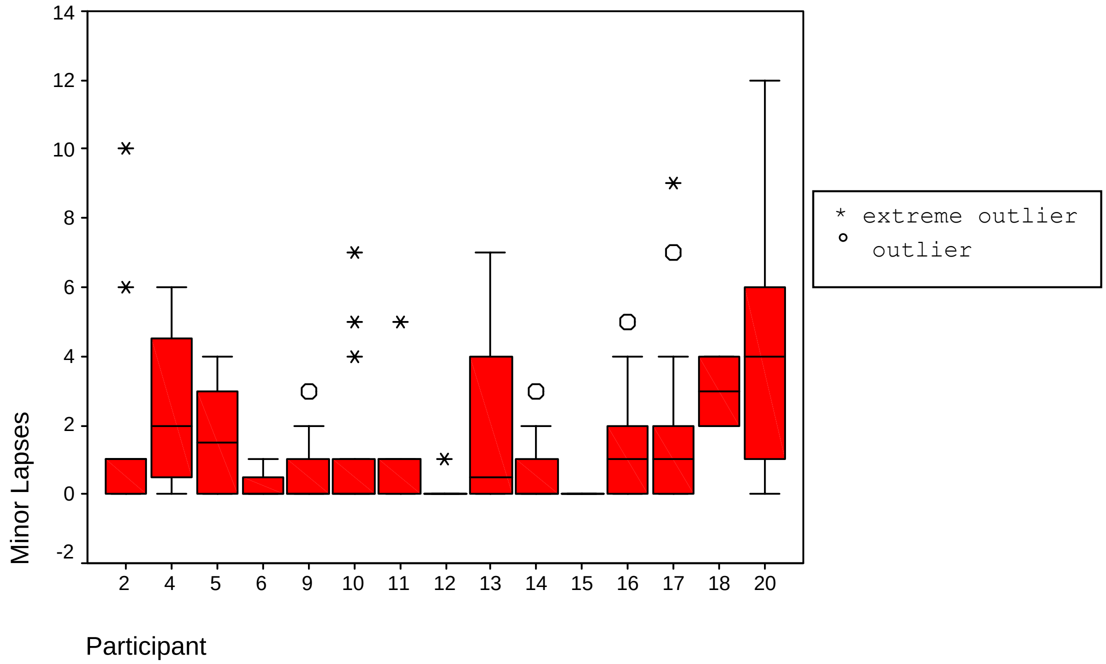

Figure 21. Boxplot: Lapses and Participant

C. SUSCEPTIBILTY TO MOTION SICKNESS

To analyze susceptibility, the Motion History Questionnaire (MHQ) was scored and then compared with the Overall MSI score. The variables used in the MHQ were motion sickness, seasickness, susceptibility, vomiting, nausea, dizziness, and vestibular illness. Other variables were not included due to missing data. Each data collection period was then analyzed separately due to different sea conditions. The hypothesis for this analysis was that a relationship exists between the MHQ and Overall MSI. The null hypothesis was that no relationship existed between MHQ and Overall MSI. To test for a relationship, the Kruskal-Wallis Non-Parametric Test was used. Overall MSI was ranked for each DCP. If the results showed a large Chi-

square and less than a 0.1 p-value, then the null hypothesis was rejected. Results are listed in Table 5 below.

Table 5. Relationship between MHQ and Overall MSI

	N	MHQ min	MHQ max	Mean	MSI min	MSI max	MSI mean	No. of Responses	Chi-square	P-value
DCP1	15	0	14	4.33	11.111	47.22	12.59	222	73.801	.000
DCP2	14	1	14	5.79	11.111	35.41	13.33	290	83.424	.000
DCP3	20	0	9	2.90	11.111	100.00	25.92	118	13.356	.064
DCP4	17	0	8	3.41	11.111	30.60	12.85	278	8.326	.305

For DCP1 through DCP3, the null hypothesis is rejected and the conclusion is made that there is a positive relationship between MHQ and Overall MSI. For DCP4, the results fail to support rejecting the null hypothesis.

D. ADAPTATION ANALYSIS

In addition to susceptibility and performance, the author wanted to determine the amount of adaptation exhibited in the motion sickness data. Line plots for three of the four data sets (Figures 20-22) compared the day to the mean and median overall MSI scores. Since research has shown that adaptation to motion typically occurs between 2 and 3 days (see Figure 10), the plots only use data through day 6. The purpose was to see if there was any downward trend of Overall MSI over time. Though Overall MSI during all three data collection periods ranged from no sickness to mildly sick, two of the three plots showed a downward trend. The most obvious of the data collections was DCP4

where it appears that the majority of the participants had adapted to motion sickness by day three.

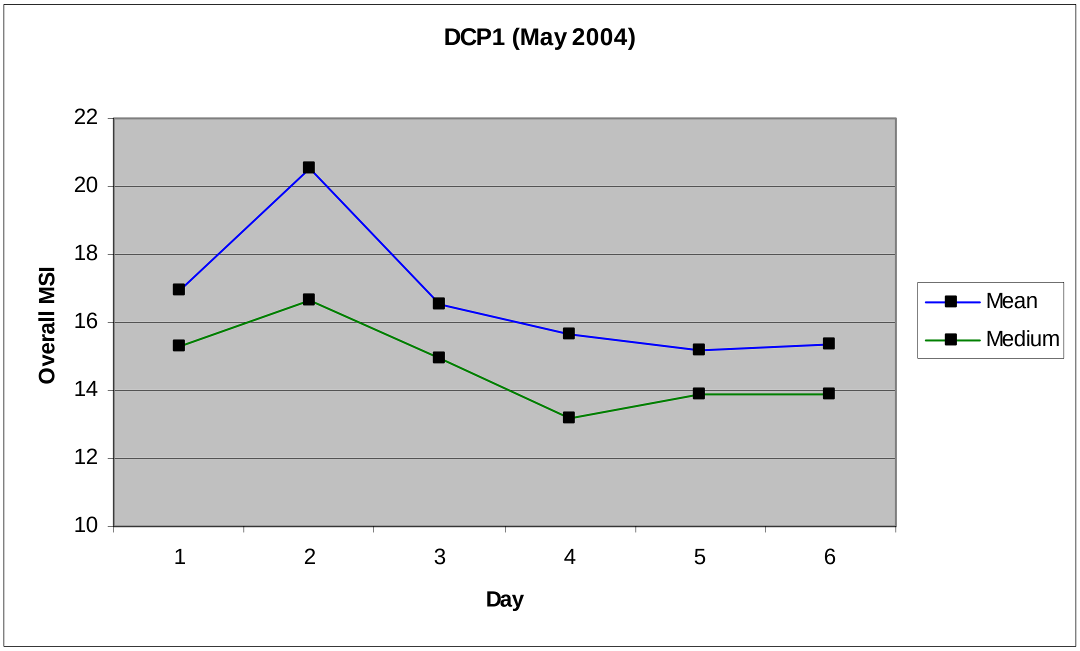

Figure 22. DCP1: Day vs. Overall MSI

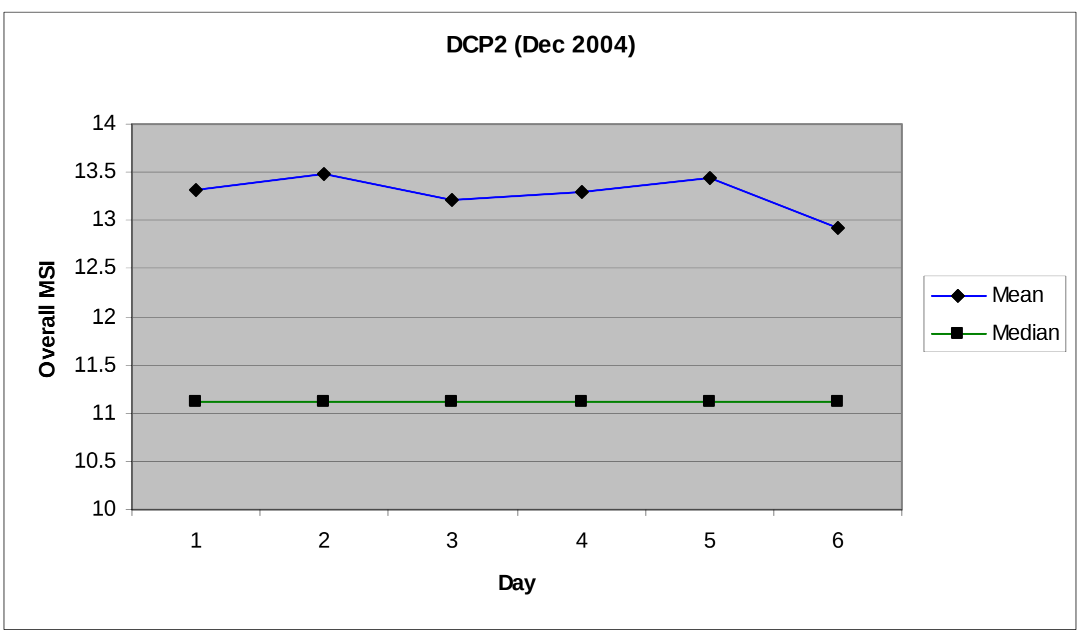

Figure 23. DCP2: Day vs. Overall MSI

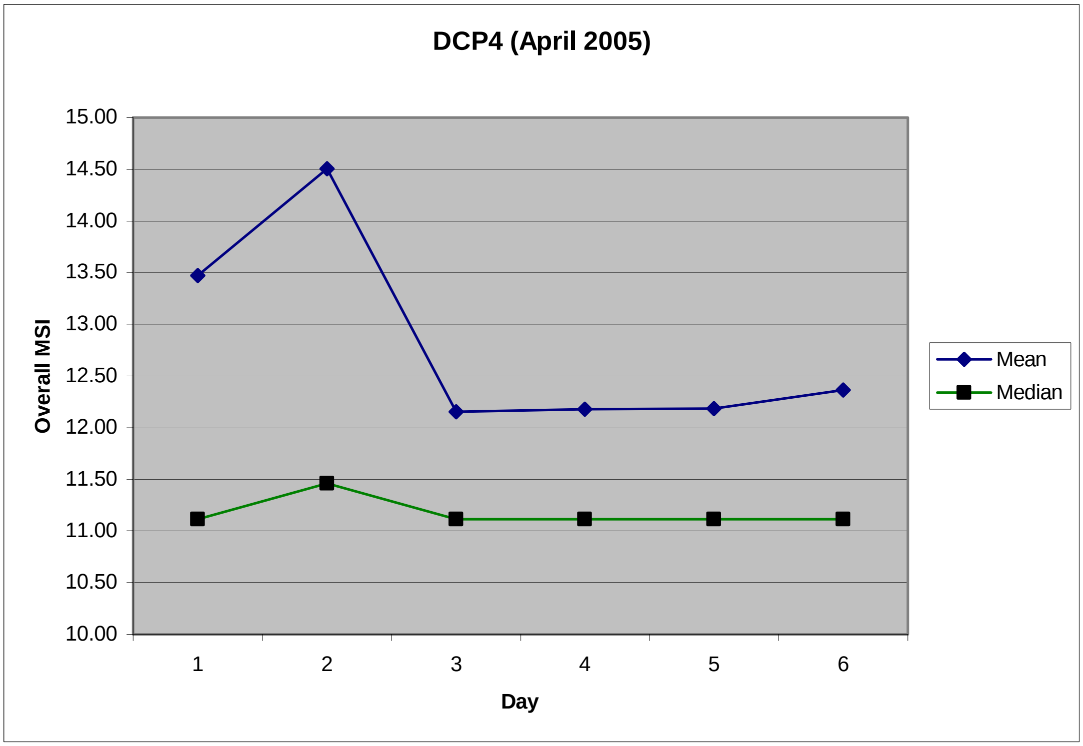

Figure 24. DCP4: Day vs. Overall MSI

V. DISCUSSION AND RECOMMENDATIONS

A. SUMMARY AND CONCLUSIONS

The literature review covered many aspects of motion sickness and the possible affects that motion sickness has on human performance. After reviewing and analyzing the effects of motion sickness on human performance, the goal was to use the relationships found in the results by applying them to future manpower models and personnel selection on minimally manned ships, specifically the LCS. A possible significant finding in this study is the relationship between the Overall MSI and Lapses on the PVT. Results suggest that a relationship may exist between Overall MSI and PVT Lapses. Further research will need to confirm this finding due to the fact that a relationship was found with Lapses and not mean RT. If future research confirms this relationship, then the PVT can be used to assess the effects of motion on PVT performance. Past research is divided on whether performance is degraded or remains the same from motion effects. By using Lapses on the PVT, it appears that performance is affected by motion sickness.

Results of the Lapses and Overall MSI agree with the NATO study conducted by Colwell (2000). Colwell’s findings indicated that there were performance problems with sailors who experienced motion sickness. He reported a concern of jeopardizing a ship’s mission with a reduced manned ship (Bos et al., 2002).

In using DCP1 through DCP4 to analyze susceptibility and adaptation, results were fruitful. Results showed that it is possible to predict MSI with the MHQ with 3 of 4 DCP

showing significant relationships between the MSI and MHQ. Results also showed that adaptation to motion onboard the HSV2 SWIFT occurs within the typical 2 to 3 day period. Again of note is that three of the four studies were conducted under calm conditions. The other study was conducted under heavy, but steady seas. Overall MSI scores were not as high as expected, but a trend showed that adaptation to the ship motion still occurred over the first 2 to 3 day period. For future research, using more participants will allow for a more accurate analysis and conclusion.

A goal of this thesis was to determine if Navy manning models needed to include the effects of ship motion on crew performance. Considering previous research and the relationship found between Lapses and Overall MSI, it appears that motion sickness does an indeed have an effect on performance. However, concluding that the motion sickness effects on crew performance must be taken into account when considering manning and personnel selection on future vessels is not yet possible.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

There is a need for future research in this area to ensure that future manning models for reduced crew size properly account for the temporary loss of personnel due to motion effects.

Different issues hindered the four data collection periods. Sea state during DCP1 was optimal; however, DCP2 was a MIW exercise that required low speeds and DCP4 was an Atlantic transit which had minimal sea states. DCP2 and DCP4 resulted in the lowest percentage of Overall MSI

scores during the first two days underway, 20% and 23.5% respectively. Additionally, there were few participants for each period, given the total possible participants onboard the ship. Over the four periods, 17.6% of the participants decided to drop out after receiving the initial brief.

To deal with these issues and make future collection periods more beneficial, it is recommended that future data collection periods occur over at least a 3 to 6 month period. By collecting data over a longer period of time, participants will be able to provide more data, potentially increasing the benefits of the study. Also, by conducting the study over a longer period of time, ships will be more likely to experience both smooth and rough weather. By entering and exiting ports frequently, researchers will be able to see if the adaptation phase is consistent. Another possible way to increase the number of participants and reduce attrition is to offer incentives to the ship and crew for participants who complete the entire study.

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APPENDIX A. SEA CONDITIONS 11-22 MAY 2005

Octagon	Octagon start time (LT)	Octagon end time (LT)	Date (PT)	Octagon start time (PT)	Octagon end time (PT)	Wave Average Sig Height (ft)	Wave Average Period (sec)
1	05/11/04 17:08	19:30	05/11/04	08:08	05/11/04 10:30	8.39	8.3
2	05/11/04 20:57	23:15	05/11/04	11:57	05/11/04 14:15	8.31	8.6
3	05/12/04 07:56	10:15	05/11/04	22:56	05/12/04 01:15	8.03	8.2
4	05/12/04 11:43	14:00	05/12/04	02:43	05/12/04 05:00	7.91	8.2
5	05/13/04 12:33	-	05/13/04	03:33	05/13/04 -	9.78	11.0
6	05/13/04 17:38	19:50	05/13/04	08:38	05/13/04 10:50	9.84	11.7
7A	05/13/04 21:26	-	05/13/04	12:26	05/13/04 -	9.57	11.7
7B	05/14/04 06:58	-	05/13/04	22:58	05/13/04 -	7.07	9.1
8	05/14/04 08:55		05/14/04	00:55	05/14/04	6.49	9.1
9	05/14/04 14:37		05/14/04	06:37	05/14/04	6.43	8.0
10	05/14/04 19:41		05/14/04	11:41	05/14/04	6.21	6.8
11	05/15/04 07:57		05/14/04	23:57	05/14/04	6.69	10.2
12	05/15/04 13:51		05/15/04	05:51	05/15/04	7.99	10.2
13	05/15/04 17:21		05/15/04	09:21	05/15/04	7.55	10.2
14	05/15/04 20:51		05/15/04	12:51	05/15/04	7.98	10.2
15	05/16/04 06:15		05/15/04	22:15	05/15/04	8.51	8.5
16	05/16/04 11:47		05/16/04	03:47	05/16/04	9.56	10.2
17	05/16/04 15:10		05/16/04	07:10	05/16/04	9.22	9.7
18	05/16/04 18:57		05/16/04	10:57	05/16/04	8.75	9.7
19	05/17/04 06:49		05/16/04	22:49	05/16/04	8.89	8.0
20	05/17/04 11:21		05/17/04	03:21	05/17/04	9.05	9.1
21	05/17/04 18:42		05/17/04	10:42	05/17/04	5.92	9.7

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APPENDIX B. SEA STATE TABLE

General	WIND			SEA								
				WAVE HEIGHT								
Sea State	Beaufort Wind Force	Range (knots)	Wind Velocity (knots)	Average Wave Height (m)	Significant Wave Height (m)	Average 1/10 Highest Wave Height (m)	Significant Range of Periods (sec)	Period of Maximum Energy of Spectrum	Average Period	Average Wave Length (m))	Minimum Fetch (nmi)	Minimum Duration (hrs)
0	1	1 - 3	2.0	0.0	0.0	0.0	up to 1.2 sec	0.7	0.5	0.3	5.0	0.3
1	3	7 - 10	8.5	0.2	0.3	0.4	0. 8 -5.0	3.4	2.4	6.1	9.8	1.7
2	4	11 - 16	13.5	0.5	0.9	1.1	1.4 - 7.6	5.4	3.9	15.8	24.0	4.8
3	4	11 - 16	16.0	0.9	1.4	1.8	2.0 - 8.8	6.5	4.6	21.6	40.0	6.6
4	5	17 - 21	19.0	1.3	2.1	2.7	2.8 - 10.6	7.7	5.4	30.2	65.0	9.2
5	6	22 - 27	24.0	2.4	3.7	4.9	3.7 - 13.5	9.7	6.8	48.8	130.0	14.0
6	7	28 - 33	28.0	3.4	5.5	7.0	4.5 - 15.5	11.3	7.9	64.6	230.0	20.0
7	8	34 - 40	38.0	7.6	12.2	15.2	6.02 - 20.8	15.4	10.7	119.5	600.0	38.0
8	9	41 - 47	44.0	11.0	17.7	22.3	7.0 - 24.2	17.7	12.5	162.8	960.0	52.0
9	12	64 - 71	>64.0	> 24.4	> 39.0	> 50.0	10.0 - 35.0	26	18	-	-	-

(From: Littoral Combat Ship, 2003)

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APPENDIX C. LCS ENVIORNMENTAL TABLE

Good Environment	Typical Environment	Poor Environment	Arctic Environment
Clear Sea State 0-4 No ECM	Light Rain Sea State 3-5, Light to Moderate ECM	Moderate Rain Sea State 6, Heavy ECM	Light Snow Sea State 3-5, MIZ (50%), Light Topside Icing, Moderate ECM
Wind Light (Friendly EM Light)	Wind 20 Knots (Friendly EM Moderate)	Wind 30 Knots (Friendly EM Heavy)	Wind 50 Knots (Friendly EM Moderate)

(From: Littoral Combat Ship, 2003)

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